Upgrading the Flow Measurement System at the Tehama Colusa Canal Authority

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Abstract

The Tehama Colusa Canal System in northern California diverts water from the Sacramento River for use by various water districts across the region. The canal system is owned by the U.S. Bureau of Reclamation (USBR) and operated by the Tehama Colusa Canal Authority. The dam at Red Bluff is owned and operated by the USBR. Within this arrangement exists a network of release structures and pumps that frequently result in complex flow conditions in the canals and pipes that deliver water to the districts. Because of these dynamic conditions, automated flow instrumentation was needed to accurately measure the flow rate so that the total water volume could be accurately determined. We provide an initial description of the problem, the evaluation process of available technologies, and some results following the implementation of the new measurement technology at 23 sites.

Keywords

Doppler, canal, velocity, flow, shallow water, discharge, flow, Argonaut, irrigation, pipe

Introduction

The Tehama Colusa Canal Authority (TCCA)'s mission statement is: ". . to secure, protect, and develop dependable and affordable sources of water and to operate, maintain, and improve the works essential to deliver such water." Operating two canal systems for the USBR (the Tehama Colusa Canal, 110 miles long and the Corning Canal, 15 miles long), the combined system serves 17 water districts in northern California. For many years the system relied on gravity-fed Sacramento River water from releases at the dam at Red Bluff. However, because of regulations implemented in the late 1990's, the USBR could no longer rely solely on these releases and so installed four pumps with a total capacity of about 400 cfs. With peak irrigation demand between 800 and 1000 cfs, some creative hydraulics had to be implemented to assure uninterrupted delivery.

The solution involved installing an automated control system with both upstream and downstream control. Target elevations are maintained both upstream and downstream of the gates on any given pool. The resulting system is fairly stable and flows can reach 1700 cfs over the 110 mile stretch meeting the needs of the various districts. However, because the system no longer relies solely on gravity, complex flow conditions with reversals and stratification became the norm which required an evaluation of new discharge metering technologies that could work accurately under these conditions.

I. Metering Practices and Evaluation

Along the canal system there are more than 70 turnouts that presently use Venturi meters with Badger recorders as the principal measurement device. Each turnout is unique; however, they all have an undershot gate coming from the TCCA Canal. The entrance gate is typically fully opened and the flow controlled downstream of the gate. The turnouts have a straight run of large diameter (2-5 ft) pipe that varies in length. Some installations are greater than 15 diameters in distance between the gate and the first obstruction. Some turnouts have a common discharge manifold with other having up to three different discharge manifolds.

At each location there is a Venturi meter used for flow measurement. The Venturi meters have been in place since the installation of the turnouts over thirty years ago. The venturi meters are mostly located downstream of screens and pumps and are located in a vault 10-30 ft underground. The vaults have only limited room to access to the actual pipeline. Venturi meters work by measuring a differential pressure between two adjacent locations with different diameters. The field method for checking the accuracy of the Venturi system is by use of a Pitot tube that has an accuracy of +/- 3%.

While the installation, calibration, and maintenance of the Venturi system is a commonly understood practice, increasing human resources costs for service and training was causing concerns. Venturi systems frequently get clogged, must be purged of air at all times, and create limitations to the distribution system because of the requirement for a reduction in the channel diameter. In addition, new California safety regulations for work within confined spaces is adding to the ongoing costs. Thus, there was strong interest in moving away from this technology to reduce overall cost and maintenance.

II. Flow metering technologies considered

Several different technologies were considered for this project including acoustic, magnetic, and modified Venturi systems.

The first technology evaluated was a modified Venturi system with updated recording electronics as the Badger instrumentation was obsolete. The ongoing safety issues with accessing the vaults was the overriding reason to dismiss this option.

Electromagnetic technologies were also considered. Two basic types were evaluated:

1) Insertion
2) Full bore

Both types work using the principle of Faraday's law. Water flowing through a magnetic field of known strength will induce an electrical current proportional to the water velocity. The insertion type will measure the velocity (and level if equipped with a pressure sensor) at a specific point near the area where it is immersed. These instruments were trialed on site; however, they could not get a good reading due to the turbulent conditions that existed at the measurement point. There were also some concerns about their vulnerability to debris because they are installed near the center of the channel.

The full bore type was eliminated from consideration because the combined purchase and installation cost was prohibitive to what the project could realistically support.

The last type of technology to consider were acoustic methods – including two types of Doppler instruments as well as the travel-time velocity sensors.

Travel-time works by locating active and passive transducers on either side of a channel and measuring the amount of time it takes for the sound to travel between them. Knowing the fixed distance between the transducers as well as the speed of sound in water, the measured travel time is then proportional to the water velocity. This method is well known for providing highly accurate measurements. Installation and calibration requires good access to the inside of the pipe or channel. Because there were both safety and cost concerns about access, this option was dismissed.

Acoustic Doppler instruments work by reflecting sound energy off suspended solid matter that exists in the water. A transmitted pulse of a known frequency is emitted into the water and then a return frequency with a Doppler shift is received after reflection from these particles. The water velocity is directionally proportional to this Doppler shift. The technology works much in the same manner as police radars (tracking speeding cars) or weather radars (tracking clouds). For water velocity measurement, there are two general types: continuous wave, or pulsed.

Continuous wave instruments work by constantly sending out sound energy without regards to any timed interval. The return echo (and subsequent Doppler shift) is taken from whichever reflective target provides the strongest signal. In many cases this is the water's surface but it can also be the portion of the water column that has the most debris. In both these cases the speed measurement may be biased towards the stronger reflective area.

In contrast, pulsed Dopplers use a timing controller to emit sound at prescribed intervals. The instrument then "gates" the return echoes so it can tell where in the water column the reflection comes from. The advantage to this is that there is no bias on any particular portion of the water column and the instrument can automatically account for stratification in the velocity profile which is imperative for accurate velocity measurements under complex hydrological flow conditions. The disadvantage to this technology is that because it was developed for research/academic use, some of the useful features required for flow measurement are not yet developed or implemented for practical use in irrigation.

After some research and evaluation, TCCA settled on the SonTek Argonaut-SW instrument; however, only after SonTek agreed to some necessary modifications to the product to make it more suitable for the needs within TCCA. This involved incorporating a new feature into the firmware and software that would enable a minimum flow threshold for total volume. Thus, only flow values above this threshold would be reported as total volume.

III. Description of the Argonaut-SW

The Argonaut-SW is a bottom-mounted pulsed Doppler system that is ideal for complex flow sites (those with large stage variation or stratified flow), or for sites where purely theoretical discharge calculations are desired. One thing that makes the SW unique is that the entire instrument is self contained within one housing – there is no remote electronics unit like there are with all the other instruments evaluated. This greatly facilitated installation and set up.

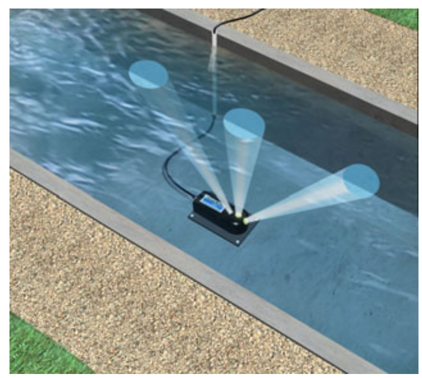

Figure 1 (left) shows the Argonaut-SW. Figure 2 (right) shows an installation site at an irrigation channel

The Argonaut-SW was designed with the following basic considerations:

- Operation in a wide range of water depths, with the minimum depth less than 1 ft.
- A vertically-integrated velocity cell covering most of the water column
- Accurate water level measurement
- Flow calculations for multiple channel types including trapezoidal, natural streams, and round/elliptical pipes

The Argonaut-SW uses two acoustic beams for velocity: one pointed upstream and one pointed downstream. The instrument is aligned with the axis of the channel. Small errors in alignment have negligible effect on velocity data since the velocity error is proportional to (1-cos(θ)) where θ is the error in alignment angle. Using two beams for velocity, instead of a single beam aimed forward, greatly reduces sensitivity to tilt angles in the installation. A third acoustic beam is aimed vertically up and is used to measure water level based on the timing of the reflection from the surface. The Argonaut-SW beam configuration is illustrated in fig. 2.

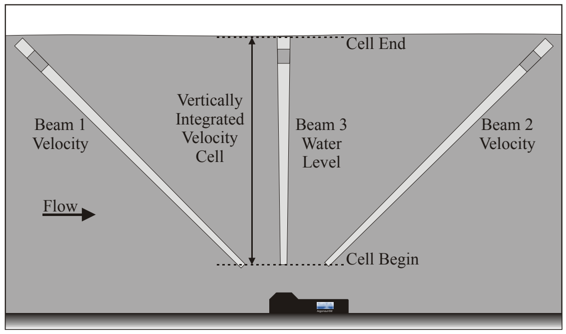

Figure 3. Argonaut-SW Beam configuration

To adapt to changing water level, the Argonaut-SW uses water level data measured by the vertical acoustic beam. The size of the sampling volume is automatically adjusted in real time to allow the Argonaut-SW to measure the greatest possible portion of the water column. The velocity measurement starts .23 ft (7 cm) above the sensor head (the acoustic blanking distance of the Argonaut-SW), and continues to the water surface. The instrument returns a single integrated velocity value representing an average over this portion of the water column. An optional feature is also available that returns velocity in up to 10 user programmable cells through the water column.

Because it was designed for small open channels, irrigation ditches, and culverts, the SW is as compact and low-profile as possible. Using an acoustic frequency of 3.0 MHz, its housing size is 9.7" x 4" x 2.5" (24.6 x 10.2 x 6.4 cm).

Because the SW is a pulsed Doppler instrument, it is able to provide a profile of the water velocity along the section of the water column where it is placed. This allows the SW to account for velocity stratifications in its internal flow calculations based on the channel cross-sectional area. Test data demonstrating this effect are shown in Figure 4.

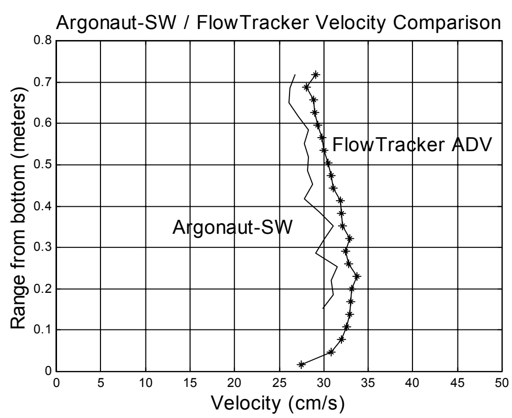

Figure 4. Velocity Profile Comparison

These data were collected in a re-circulating flume with water depth of about 2.3 ft (0.7 m). The Argonaut-SW was mounted on the bottom, slightly off center. A FlowTracker ADV was manually raised and lowered to measure the current profile at the same location along the length of the flume; the ADV measurement location was 0.7 ft (0.2 m) to the side of the Argonaut-SW. The data shown in fig. 4 represent the average profile over a period of more than 1 hour.

The offset between Argonaut-SW and ADV velocity data (.0.07 ft/s or ~2 cm/s) is attributed to variations in the velocity field across the width of the flume, and is consistent with other flume data. The important comparison is the consistent shape of the velocity profile, particularly in the top half of the water column. In this case the Argonaut-SW is able to accurately measure water velocity all the way to the water surface, with no evidence of side lobe interference. Side lobe interference comes from undesired acoustic energy that propagates in direction other than the main beams. This is naturally occurring in any acoustic system; however, SonTek has taken steps to minimize this effect in their design. Tests in other flow conditions have shown similar results.

It is important to note that the SW can only make measurements all the way to the surface when the vertical beam can reflect off the free water surface only. In full pipe conditions, the hard reflective surface of the pipe wall contaminates the signal return. For these situations, a setting within the SW enables it to ignore that portion of the velocity profile near to the hard boundary. Velocity information is then extrapolated based upon the measured portion and accurate flow readings are still possible.

At its core, the Argonaut-SW measures water level and water velocity. To measure flow, the user is required to input the cross section of the channel (irregular, trapezoidal, elliptical, etc) and the SW will compute the area based upon the water level it measures. Velocity information is then applied and the SW computes flow in one of two methods:

1) Theoretical, based upon published flow formula
2) Empirical, based upon development of velocity index ratings

The empirical method is relatively new, deriving a specific flow equation for a given channel based upon independent flow measurements. If carried out properly, the end result is very accurate flow measurements with estimates of uncertainty based on the calculation method. The procedure is described by numerous papers including ITRC 006-003 *Non Standard Structure Flow Measurement Evaluation using the Flow Rate Indexing Procedure*. Once the proper equation is derived, the information is loaded into the SW for real time flow data output.

While the Argonaut-SW had a solid track record in the Western U.S. for flow measurement in open channels, TCCA could not make practical use of the device because of some shortcomings in the way it reports data. While the SW had been able to compute flow since its inception, it was never used for total volume measurements in such a complex flow setting. The basic problem TCCA was having had to do with timing of the pump operation and its effect on the flow in the pipes. At certain times between pump cycles or after one had shut down, the velocity of the water would start to acquiesce. This would often be accompanied by an event of back and forth motion at very low velocities. If the instrument would continue to accumulate volumetric data through this event, significant errors would be reported in the total volume. Thus the firmware modification to provide a low velocity threshold was necessary to provide a continuous record of accurate flow volume.

IV. Flow Meter test

In conjunction with Tehama Colusa Authority and Westside Water District, USBR personnel conducted two flow measurement tests. The initial test occurred December 21, 2005 using four different meters. A known volume of water was pumped into a holding tank and the accuracy of the meters was checked following each test. After extensive evaluation of the data collected, it was decided to conduct further testing isolating the SonTek Argonaut-SW Acoustic Doppler Meter. This testing occurred on January 13, 2006. The goal was to pump a continuous flow of water into the holding tank, varying the flow until a known volume of water was achieved. The SonTek and Venturi Meters were then compared to the known volume in the holding tank. Both meters recorded acceptable totals.

Based on the tests, Westside Irrigation District noticed that there were some discrepancies with their field current meters (mechanical) and decided to refurbish eight out of the nine field units. Their goal was to obtain volume totals similar to the Venturi Meter. Following the refurbishment, the field meters reported a negative 4% difference from the Venturi Meter. The time span allowed for the data to be collected was from April 30, 2006 to October 31, 2006.

USBR commends Westside Irrigation District for the work they have done refurbishing their field meters. The improvement from 9%-15% to 4% accuracy and the testing that was done confirms the fact that a maintenance program on all meters is the utmost importance for achieving acceptable results.

V. Installation, data and index velocity procedures

At the time of this writing, five SonTek SW instruments have been installed into the network and data has been collected and processed using index velocity procedures. The purpose of this limited deployment was to evaluate the instrument setup, and process some data to increase the users understanding of these devices so that some more standardized procedures can be applied to the remaining sites in the network. The present plan is to install an additional 45 meters into the TCCA network.

Figures 5 & 6: Photos show the installation into the one of the TCCA sites. The photo at right shows the Argonaut-SW cradled in a protective "shoe" that helps deflect debris away from the instrument

The TCCA currently calibrate flow measured by the SW using the Venturi meters which are recorded by Badger Instruments. As indicated previously, the Badgers are failing with replacement parts unavailable. Prior to undertaking the Velocity Index calibrations, ITRC personnel verified the accuracy of the Venturi meters, which is +/- 6% under the best of operating conditions. While a data review of the Venturi meters showed the instantaneous values to be very good, the Venturi showed some discrepancies under the constant flow tests.

Its believed that the discrepancies may be due to that fact that the flow was not actually at a constant rate due to water being pumped into the bottom of the tank.

For the velocity-index method, the measured velocity is sampled and recorded in programmed time intervals concurrently by both the device being calibrated (e.g., an Argonaut SW upstream of the pumps) as a continuous monitoring instrument and a second device or devices measures the simultaneous discharge measurement. In most cases these are portable devices which are capable characterizing the flow over the entire channel cross section. In this case because of access issues, the Venturi meter located downstream of the pumps was used. Mean velocities can also be obtained from other techniques such as pitot tube measurements, propeller meters, or other hydroacoustic instruments as long as the time periods are the same.

Using the SonTek FlowPack Velocity-Index Rating program, the resulting data for multiple sets of mean velocity and index velocity collected over a range of flow are analyzed using regression techniques. The resulting equation of the index velocity rating can then be utilized by the Argonaut-SW's internal flow computation feature. Every location will have its own specific index velocity rating, enabling data with the lowest uncertainty achievable.

Some data collected from an Argonaut-SW installed in a 42" pipe (107mm) at the Westside Irrigation District is shown below.

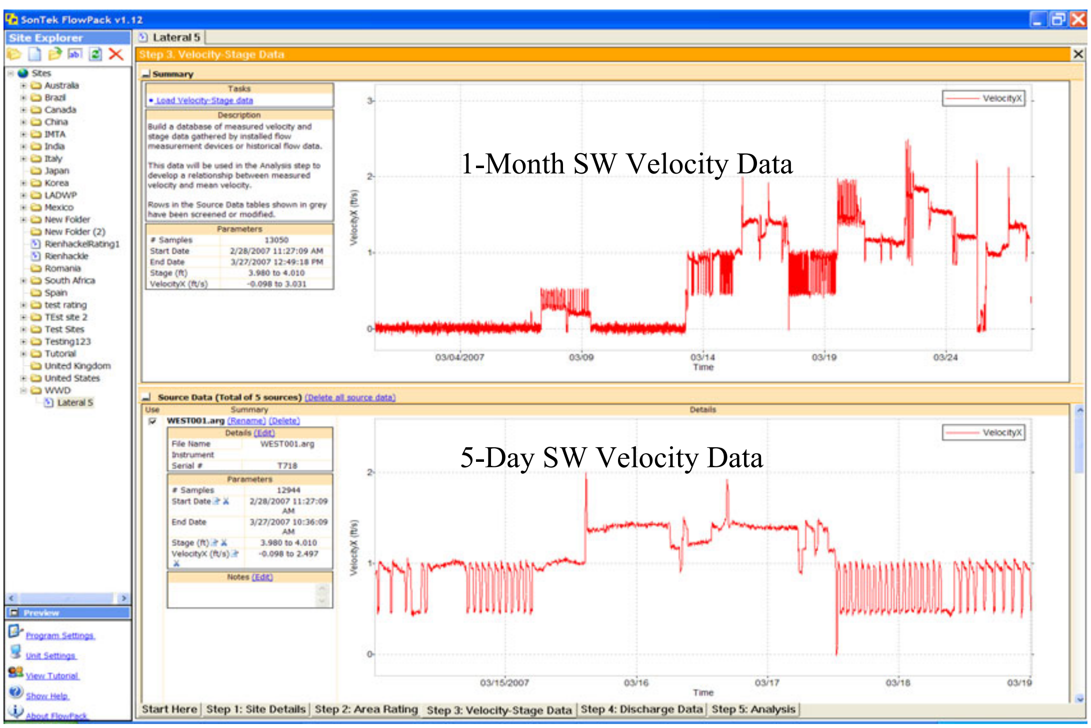

Figure 7: Plot showing velocity time-series data for Westside Water District Lateral 5.

Figure 7 shows the time-series velocity data measured by the Argonaut SW in a 42-inch pipe (Lateral 5) in the Westside Water District. The top velocity plot represents 1-month of continuous SW velocity data. The lower plot shows a 5-day excerpt of the 1-month data. The lower plot better shows the quick response of the Argonaut SW to the true variations in the pipe caused by changes in pump operating conditions.

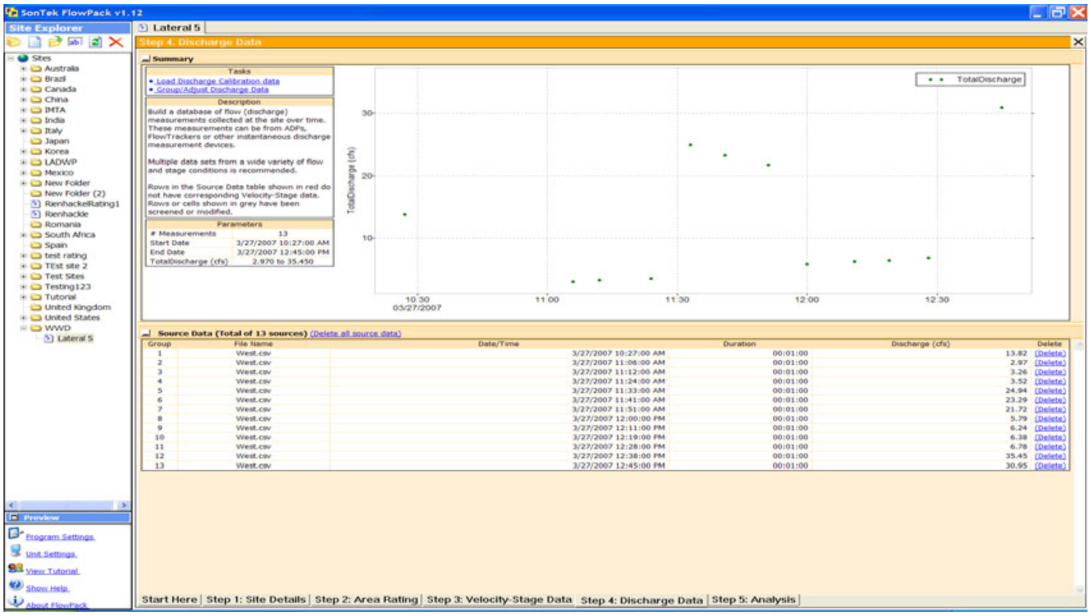

Figure 8: Discharge calibration data for Westside Water District Lateral 5.

Figure 2 shows the calibration data used to develop the mean-velocity rating for the Argonaut SW. The data were measured using a Venturi ranging in flows from 2.97 cfs to 35.45 cfs and were made concurrently to the operation of the Argonaut SW.

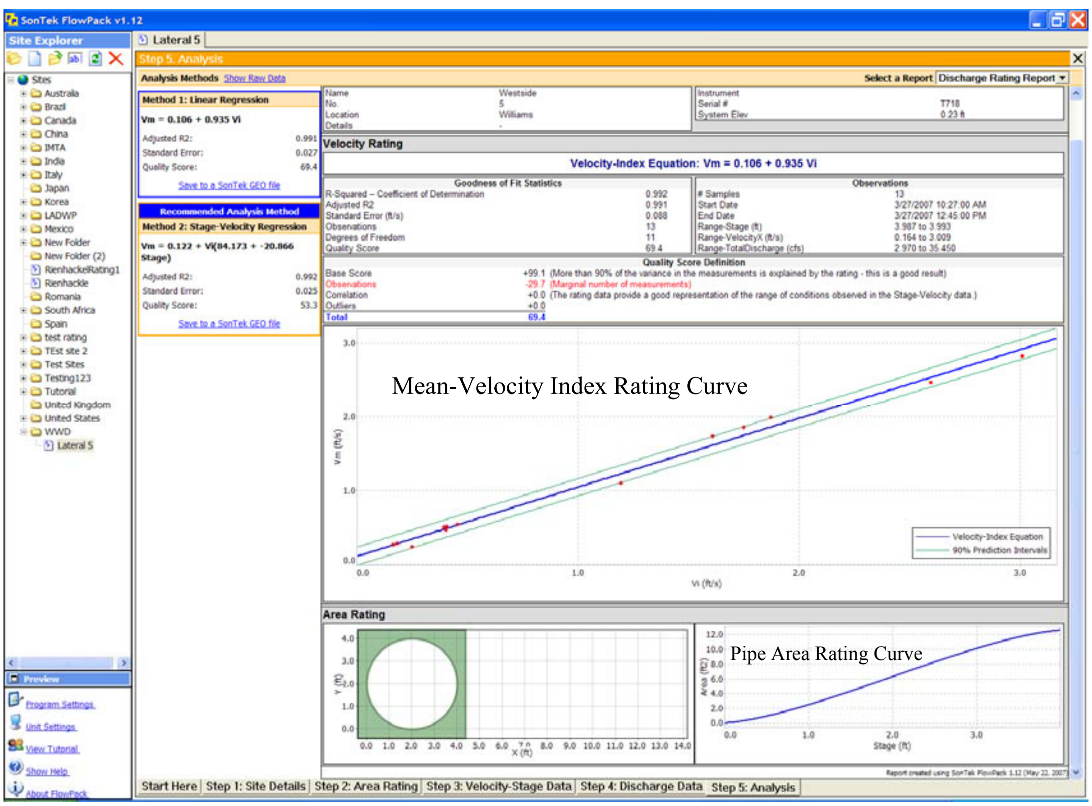

Figure 9: FlowPack discharge rating summary for Westside Water District Lateral 5.

Figure 9 shows the result of mean-velocity rating development using SonTek FlowPack Velocity index rating software. The figure shows the resulting mean-velocity and area rating curves used to calculate flow in the pipe (Lateral 5). Note that the linear regression is represented by the blue line and the light green lines represent the prediction intervals. One of the basic premises of velocity indexing is that the rating will improve over time with more concurrent measurements.

VI. Conclusion

More data needs to be collected and some of the procedures refined but from the USBR perspective, the data form the Argonaut-SW shows what was originally expected. That is, it very accurately characterizes what is going on inside the pipe and is able to properly exhibit the starting and stopping of the pumps. This is especially true when a pump shuts down, and then starts up again and the flow then sloshes back and forth for a period of time. The new features implemented by SonTek that set a flow measurement threshold for the recording of total volume worked perfectly in the applications thus far.

Though not shown within the data of this paper, we were also able to observe that the more pumps involved in a particular flow event, the more complicated the flow dynamics are within the pipe and this was exhibited in some of the data sets collected by the Argonaut-SW.

The velocity-index process is extremely valuable to an application such as this where there are numerous flow conditions to account for. Having a readily available software package like FlowPack that tracks ongoing data collection and provides the regression was highly useful to both the personnel in the field, and the operators who were evaluating the collected data.

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